

# **Time Series Observations of Currents in the Bering Strait and Beaufort/Chukchi Seas**

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## **LONG-TERM GOALS**

Our long-term research goals are to understand the circulation and physical properties of the high-latitude ocean, both mechanistically and quantitatively. We also seek to understand the links between physical mechanisms, including those affecting the ice cover and the biology and chemistry of the high-latitude marine environment. The variability of the marine environment is a special focus and concern.

## **OBJECTIVES**

Our three major objectives are closely related, reflecting the three grants on which we are reporting.

Our first objective is to analyze data from the western Arctic Ocean and its adjacent seas in order to provide a measure of the variability of the shelf-basin system that is observationally based; identify, and where possible quantify, the important physical mechanisms controlling this system; contribute to the Shelf-Basin Interaction initiative (SBI), particularly in understanding the mechanisms of shelf-basin exchange; and promote further improvements in the rapidly growing array of models of arctic circulation and hydrographic structures and their variability, including providing patterns and statistics against which to test the fidelity of these models.

Our second objective is to extend direct measurements of transport, temperature, and salinity in Bering Strait, supplemented by time series measurements of ice-thickness and of *in situ* nutrients and optics using upward-looking sonars, a nutrient analyzer, and optical sensors. This upstream information is vital to the SBI initiative since the influx of Pacific waters provides a key forcing for the western Arctic shelf-slope-basin system, including its biogeochemistry. We note that a particularly important dynamical aspect of the Pacific water presence in the Arctic Ocean is its contribution to stabilizing the upper ocean, thereby influencing ice thickness and upper ocean mixing.

Our third objective is to make moored measurements of velocity, temperature, salinity, and ice drift in the northern Chukchi Sea during 2002-2004 in support of SBI Phase 2. Our focus is on the transformation and outflow from the shelf of Pacific waters that have entered through Bering Strait. These measurements will also contribute toward the broader goals of SBI by providing the temporal context for the shelf source waters as they enter the core SBI outer shelf and slope region.

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## APPROACH

Together with T. Weingartner (University of Alaska) we are analyzing and synthesizing a historic set of moored time series and hydrographic data from the western Arctic shelves, slopes, and adjacent deep basin. The synthesis addresses the circulation and water properties, with emphasis on the system dynamics, the climatology and statistics of the various fields, and the variability of the system, especially seasonal and interannual. In addition to refereed manuscripts and presentations at meetings, we will make this data set accessible via our web site and through the established data centers.

We are also maintaining instrumented moorings in Bering Strait. In conjunction with earlier measurements, these are providing near-continuity in the record of flow and water properties in the strait over more than a decade. Velocity, temperature, and salinity are the core physical measurements at each mooring, supplemented with ice thickness measurements using upward-looking sonar, *in situ* nutrient analysis, and optical measurements (cf., the related project section). Two moorings are being maintained in the eastern channel and a third mooring north of the Diomed Islands, just east of the Russian EEZ, a location that serves as a surrogate for the western channel. Together with extensive shipborne hydrographic and ADCP measurements made each year, this combined array provides information on cross-stream variability and spatial scales, both of the flow and of the water properties in the strait.

Together with T. Weingartner, we are making moored time series measurements within the primary throughflows on the northern Chukchi shelf [Barrow Canyon (ca. 80 m depth), the Central Channel (ca. 50 m), and on the north-central shelf, downstream of Herald Valley (ca. 70 m and 110 m)]. The moorings include current meters (fixed-depth and profiling with bottom tracking for measuring ice drift) and temperature/conductivity recorders. In a closely related effort, R. Pickart (WHOI) has installed a mesoscale array on the Beaufort slope near 152°W, and J. H. Swift (SIO) is providing CTD/rosette sections to support the mooring work. The sections also include LADCP measurements, which can be detided using the mooring data. Data will be shared with other SBI investigators after calibration and data quality assurance, and will be submitted to the appropriate data centers in a timely manner.

## WORK COMPLETED

We have continued the analysis of time series from the western Arctic shelf and slope, together with a variety of hydrographic data from the area. One journal paper, dealing with the central Chukchi shelf circulation, is nearing submission to JGR. A second paper, also nearing completion, examines the Chukchi Sea in its entirety, with respect both to circulation and water mass modification.

The three Bering Strait moorings deployed in 2001 were recovered this past June from the *R/V Alpha Helix*, and three new ones were deployed. Both sets of moorings incorporate instruments for measurement of ice thickness and dissolved nitrogen, and the most recent deployment adds optical sensors. Additionally, extensive CTD and ADCP sections were taken in and north of the strait as far as Pt. Hope. Despite persistent efforts, we continue to be refused to work in the Russian EEZ, but are able to partially compensate with our mooring and station net north of the strait, which captures a portion of the flow through the western channel of the strait.

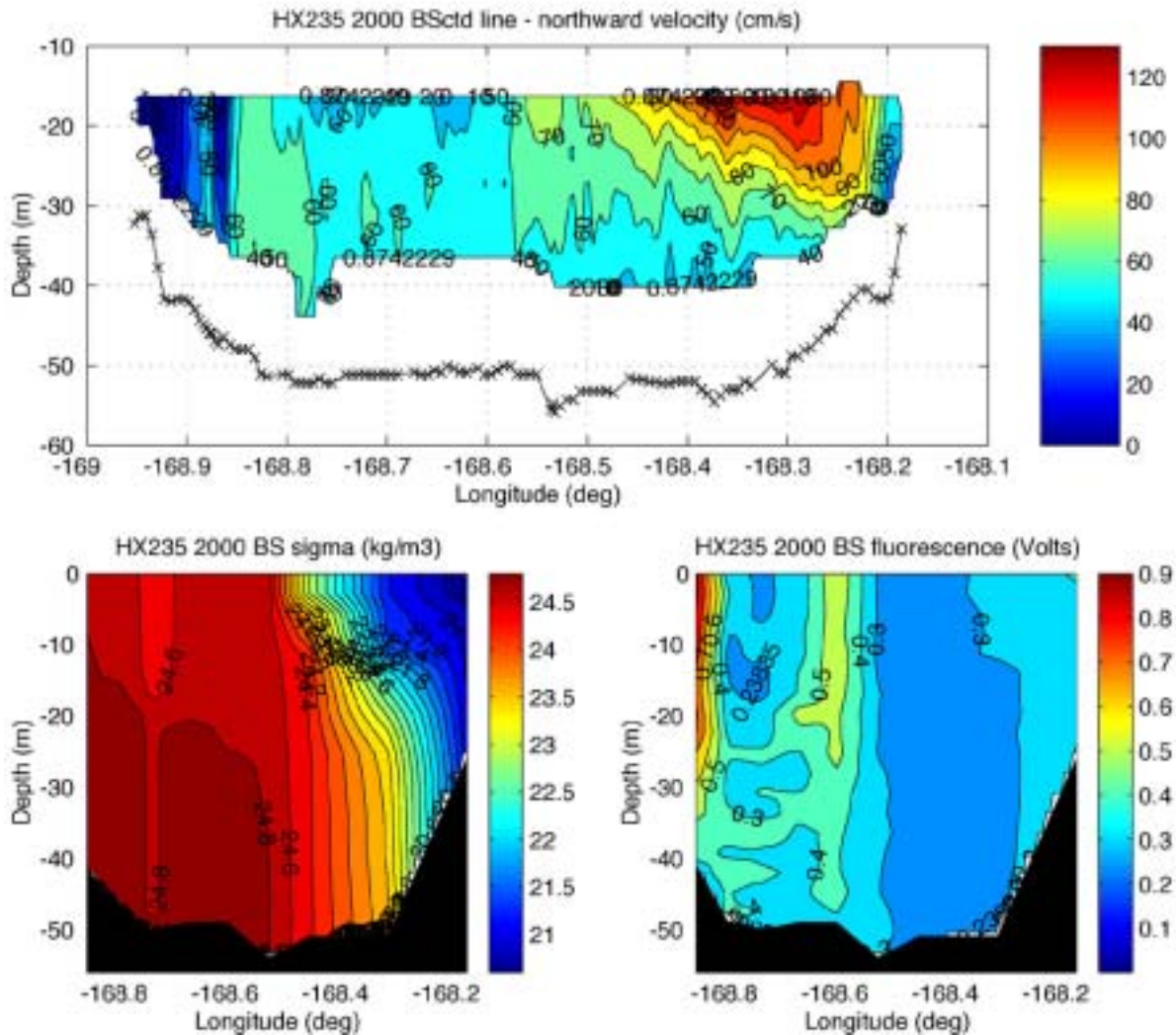
The four moorings on the northern Chukchi shelf were installed during July-August this year from the *USCGC Polar Star*, accompanied by four hydrographic sections. The program will be repeated in 2003 to provide a second year of measurements.

## RESULTS

While previous studies indicated that Pacific waters crossed the Chukchi shelf through Herald Valley and Barrow Canyon, we find a third conduit onto the outer shelf, viz., the Central Channel between Hanna and Herald shoals, which carries a mix of Bering Sea water, winter water, and Alaskan coastal water. The transport through the Central Channel varies seasonally in phase with the Bering Strait transport, and is  $\sim 0.2$  Sv on average, i.e.,  $\sim 25\%$  of the mean Bering Strait transport. Flow over the central outer shelf is northeastward in the mean, toward the shelf break, and carries water from the Central Channel and Herald Valley. This mean northeastward flow opposes the prevailing winds and is primarily forced by the sea level slope between the Pacific and Arctic oceans. Current variations are mainly wind-forced, but baroclinic forcing, particularly associated with upstream dense water formation in coastal polynyas, may occasionally be important. Winter water mass modification depends on the fall and winter winds, which control the seasonal evolution of the ice. For example, an extensive fall ice cover delays cooling, limits new ice formation, and results in little salinization. In such years, Bering shelf waters cross the Chukchi shelf with little modification. On the other hand, extensive open water in fall leads to early and rapid cooling, and if accompanied by vigorous ice production within coastal polynyas, results in the production of high salinity ( $>34$  psu) shelf waters. Such interannual variability likely affects slope mixing processes and the transport of Pacific waters into the Arctic Ocean interior.

Hydrographic sections across the outer shelf and slope during the SBI deployment cruise show modal waters at the freezing point and with salinities as high as 33.4 psu. Some of this water fluoresces strongly, corresponding to a high chlorophyll load. These waters must therefore represent recent outflow from the Chukchi shelf, and their properties are appropriate to ventilating the Arctic Ocean halocline.

Velocity and hydrographic fields observed in Bering Strait are illustrated in Figure 1. Note that the coastal jet is not always present, even in summer.



**Figure 1: ADCP (top), density (lower left), and fluorescence (lower right) sections across the eastern channel of Bering Strait, September 2000.** These sections show a strong surface-intensified jet on the eastern side of the strait in summer, with speeds twice that of the ambient flow. The jet coincides with the sharp density gradient over the base of the steepest topography, inshore from the mid-channel mooring location. These observations have led us to add another mooring at the location of the jet during the last two years. Note in the fluorescence section that a large increase is visible on the western side, just east of Little Diomedede Island. This is a signature of the high primary production within the water being carried northward through the western channel of the strait.

## IMPACT/APPLICATIONS

We seek to quantify the large variability found in the Pacific-origin waters that flush the western Arctic shelves. Much of this variability is generated in the Bering Sea, and the waters may be further modified in the Chukchi, particularly along the Alaskan coast in winter, but with large interannual variability. The shelf waters are then discharged into the Arctic Ocean, where their seasonal and

interannual variability is propagated within the Arctic Ocean, in part by the boundary current. This propagation leads to variability in regions far from the originating shelves. An understanding of these effects and processes will be vital to future conceptualizations of the Arctic Ocean.

The accumulating time series from Bering Strait, now more than a decade long, provides a remarkable record of the upstream forcing of the Chukchi shelf. The high salinities at the beginning of the 1990s have not returned. The salinity increase in 1999-2000 proved to be moderate and short-lived. Indeed, in 2000-2001 both the fall salinity minimum and the late-winter maximum were distinctly lower than in recent years. Neither has there been a return to the anomalously warm conditions of 1996-1997. Rather, the strait waters currently represent a persistently cool and fresh regime. Ventilating the deeper portions of the Arctic Ocean halocline will therefore depend on extensive freezing of the Bering Strait waters downstream on the Chukchi shelf, something which in turn depends on fall and winter ice and wind conditions.

Additionally, our work provides a framework for the analysis of chemical and biological data, it promotes improvements in modeling arctic circulation and hydrographic structures and their variability, and it provides observations against which to test the fidelity of these models.

## **TRANSITIONS**

Major goals of the SBI initiative are to understand the physical processes responsible for water mass modification over the arctic shelves and slopes and the exchanges with the interior ocean, as well as to understand the variability of this system. All three of our reported projects address this directly. Furthermore, our description of the time-dependent shelf circulation provides important guidance to investigations of shelf productivity and biochemical cycling. For example, water parcels leaving the northern Chukchi shelf will exhibit substantially different carbon and nutrient loading, depending on their trajectory and the season. Our work also addresses other prominent issues, including the flux and processing of freshwater on the western Arctic shelves, and the needs of a variety of arctic simulations for accurate long-term boundary conditions and forcing.

To facilitate the work of other SBI investigators we are making results available through refereed publications, various presentations, and our web site. The underlying time series data set is also being archived and made widely available through the appropriate national data centers.

## **RELATED PROJECTS**

Our analysis of the western arctic data set is closely coordinated with that of T. Weingartner, UAF. In the Bering Strait we continue cooperative work with T. Whitledge, UAF, through deployment of an *in situ* nitrate analyzer and optical sensors. These measurements are representative of the new techniques that will be required to illuminate biogeochemical cycles in the high-latitude ocean. We also continue our cooperation with R. Moritz, UW, through deployment of upward-looking sonars to measure ice thickness. These deployments address the need for circumpolar time series measurements of ice thickness, both to illuminate issues of ice mechanics and thermodynamics and to track changes in ice thickness that may accompany those observed within the Arctic Ocean by submarines. We further support a number of other investigators in Bering Strait by providing sampling opportunities during the mooring cruises, including L. Cooper, C. Deal, K. Falkner, and T. Tanaka.

The new SBI program on the northern Chukchi shelf is collaborative with T. Weingartner, UAF; with R. Pickart, WHOI, who is concentrating on the adjacent Beaufort shelf and slope; and with J. Swift, SIO, who is leading the hydrographic measurements.